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DEVELOPMENT OF MODULES FOR THE REFINEMENT OF MARINE CORPS CASUALTY ESTIMATES

J. M. Zouris

C. G. Blood

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NAVAL HEALTH RESEARCH CENTER
P. O. BOX 85122
SAN DIEGO, CA 92186-5122

BUREAU OF MEDICINE AND SURGERY (MED-02)
2300 E ST. NW
WASHINGTON, DC 20372-5300



**DEVELOPMENT OF MODULES FOR THE REFINEMENT OF MARINE CORPS
CASUALTY ESTIMATES**

James M. Zouris
Christopher G. Blood

Modeling and Simulation Program
Naval Health Research Center
P.O. Box 85122
San Diego, CA 92186-5122

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Summary

Problem

Models used to project ground casualties for military operations typically provide estimates of the mean numbers of daily casualties without indicating the magnitude of the likely casualty pulses or the specific types of patient conditions (PCs) that will be treated. Estimates of the daily casualty variability and the specific medical conditions likely to be seen are both needed to accurately determine the medical resources required to support a military operation.

Objective

The present effort documents casualty simulation technologies that can be used in conjunction with both the Casualty Estimation Model (CASEST) and the Ground Casualty Forecasting Model (FORECAS). Two modules have been developed for (1) assessing the daily casualty incidence variability that may be observed during combat operations, and (2) projecting the composition of a patient stream in terms of the specific traumas and illnesses.

Approach

Casualty means and distributions observed in past combat operations are used to simulate expected casualty stream variability and composition. Exponential and lognormal distributions were used to calculate the percentile estimates for battle injuries and illnesses respectively. The generation of patient streams in terms of the specific PC codes expected were accomplished by simulating a Poisson random variable given the mean rate of each PC code. The mean rate of each PC code was calculated by multiplying the total number of projected admissions by the probability of each PC code as determined from past military operations.

Results

Modules compatible with two ground casualty estimating models, FORECAS and CASEST, have been developed to project daily casualty incidence variability and forecast the specific patient conditions expected during military operations.

Conclusions

Medical resource planning models may more accurately project the needed supplies, equipment, and medical personnel by incorporating estimates of maximum patient loads and detailed information on the types of medical admissions likely to be incurred.

Development of Modules for the Refinement of Marine Corps Casualty Estimates

Accurate forecasting of the medical resources needed to support a military operation is dependent upon reliable estimates of the overall patient load and the types of medical conditions likely to be sustained. The expected number of casualties for a military engagement can be projected by software applications that take into account various scenario-specific parameters that impact casualty sustainment. Specifically, the Marine Corps Casualty Estimation Model (CASEST) is an automated tool by which a user can input combat scenarios and generate estimated casualty numbers for manpower planning purposes.¹ This model provides the capability to estimate conventional and nonconventional battle injuries as well as disease and non battle injuries (DNBIs). A second model, the Ground Casualty Forecasting System (FORECAS) similarly projects casualty incidence based on user-defined and scenario-specific parameters. Baseline wounded-in-action (WIA), killed-in-action (KIA), and disease and non battle injury (DNBI) rates within the FORECAS system are derived from casualty data collected during previous combat operations.² The empirically derived baseline rates are then adjusted to account for adversary-specific factors, and for the terrain and climate of the operational theater.

While CASEST and FORECAS project rates of WIA and DNBI for combat operations, distributions of the types of patient conditions likely to be seen during the military scenarios also need to be incorporated. Since the specific medical supplies needed to treat a patient may differ greatly depending upon the particular wound or disease incurred, projections of individual medical conditions are required to more accurately gauge the needed medical resources. Similarly needed are estimates of the magnitude of the likely fluctuations in daily casualty rates. The expected casualty "spikes" are needed because resources such as hospital beds and medical personnel should be based on estimates greater than the average likely patient load.³ Thus, the objective of this research effort was to develop and document two software modules capable of interfacing with CASEST and FORECAS which can provide the medical planner with the capabilities to project the types of patient condition (PC) codes likely to be incurred and to assess probabilities for varying levels of daily patient loads.

I. PROPOSED CASEST ENHANCEMENTS

The modular enhancements compatible with CASEST were developed using the Microsoft Visual C++ Version 6.0 platform and the Microsoft Foundation Class (MFC) library functions. The first module projects daily casualty rate variability by reading the number of casualties estimated by CASEST, and calculates percentile estimates of each attrition type. The second module utilizes the overall casualty numbers generated by CASEST and then derives a patient stream in terms of the specific PC codes likely to be observed.

A. Casualty Rate Variability Module Compatible With CASEST

The first module has been developed to read the number of casualties estimated by CASEST and then calculate percentile estimates of expected hospital admissions, ranging from the 50th to the 95th percentiles, for each attrition type. To calculate the percentile estimates, the CASEST system must first be executed by running a combat scenario to generate the estimated casualty numbers. To run a scenario, the user selects the Casualty Module from the CASEST main menu and proceeds by entering all of the required user-defined parameters. These parameters include scenario, time phase, casualty type, battle intensity, evacuation policy, and aviation support. The user also must indicate the types of casualties of interest on a subsequent input screen. The selections for casualty type include conventional casualties, nuclear/ biological/chemical, and disease/non battle injuries. After selecting the casualty type of interest, the user then proceeds to input the remaining parameters (e.g. scenario, time phase, battle intensity, evacuation policy) for the anticipated scenario. The module developed under the present effort projects the expected variability solely for conventional ground casualties and DNBI incidence.

The user then returns to the CASEST master menu to create the output file required for activation of the newly developed module; selection of this CASEST option displays the total numbers and types of casualties. Figure 1 displays a portion of the CASEST output screen that indicates the numbers of casualties for a user-defined scenario. Also, a CASEST output file is "casasgn.dbf", is generated, which is used as input for the modules under discussion. However, an object database connection (ODBC) must first be established for the program to be able to read this output file. To establish the needed ODBC the following steps must be carried out:

- Open **Control Panel** by clicking on the **Start** button, selecting **Settings** and clicking on **Control Panel**. Locate the ODBC Data Source icon and then double click the icon to open.
- Click the **User Data Source Name (User DSN)** tab, if it is not already selected.
- Click the **Add** button.
- The **Create New Data Source** dialog box appears.
- From the list, choose the driver you want to use with your database, in this case, Microsoft dbase driver (*.dbf), and then click **Finish**.
- The ODBC Setup dialog box specific to the driver you indicated appears.
- In the **Data Source Name** box, type "casasgn" without the quotation marks.
- Optionally, in the **Description** box, enter a description for the database.
- In the **Database** group box, unclick the **Use Current Directory** checkbox and click **Select Directory** button, and then navigate to the location of casasgn.dbf file, which will be in the CASEST directory.
- Click **OK** to select the database.
- Click **OK** to exit the **ODBC dbase Setup** dialog box, and click **OK** to exit the **ODBC Data Source Administrator** dialog box.

CONVENTIONAL CASUALTIES				
FORCE STRENGTH: 18800 START DAY: 1				
TYPE: MFD END DAY: 20				
GROUND COMBAT INTENSITY: H				
GROUND COMBAT EXPECTED CASUALTY RATE RANGE: A				
MEDICAL EVACUATION POLICY: R				
TOTAL CONVENTIONAL CASUALTIES				
Casualty Category	KIA	WIA	DOW	TOTAL
Ground Combat Element	327	946	20	1293
Non-Maneuverable Element	11	47	0	58
Aviation Combat Element	3	21	0	24
Total Conventional	341	1014	20	1375

Figure 1. Portion of CASEST Output Screen Indicating Numbers of Casualties Projected

After the ODBC is set up for the first time, the CASEST user may then run the casualty module (CASMOD) to calculate the potential daily casualty loads corresponding to various percentile values. The ODBC has to be established only one time prior to execution. The user

then must press the “Get Data/Calculate” button, shown in Figure 2, to activate this module. Then, based on the average number of casualties per day, the various percentiles for each attrition type (WIA, KIA, DNBI) are calculated and displayed in the appropriate boxes ranging from the 50th percentile to the 95th. Died-of-wound (DOW) casualties are counted as WIA in the application module. Figure 1 depicts results from a potential 20-day ground scenario in which there were a total of 1034 WIA casualties, representing an average of 51.7 casualties per day. The CASMOD output screen, shown in Figure 2, displays this daily average as well as the projected casualty loads corresponding to different percentile values. As can be seen from Figure 2, the 95th percentile is 155, which implies that on 95% of the days, there will be less than 155 casualties. Conversely, this value can also be interpreted to indicate that on 5% of the days the casualty load is projected to be greater than 155. The 50th percentile value, also shown in Figure 2, indicates that on 50% of the days the WIA casualty load is expected to be less than 38 patients. The statistical underpinnings of this module are detailed later in this report.

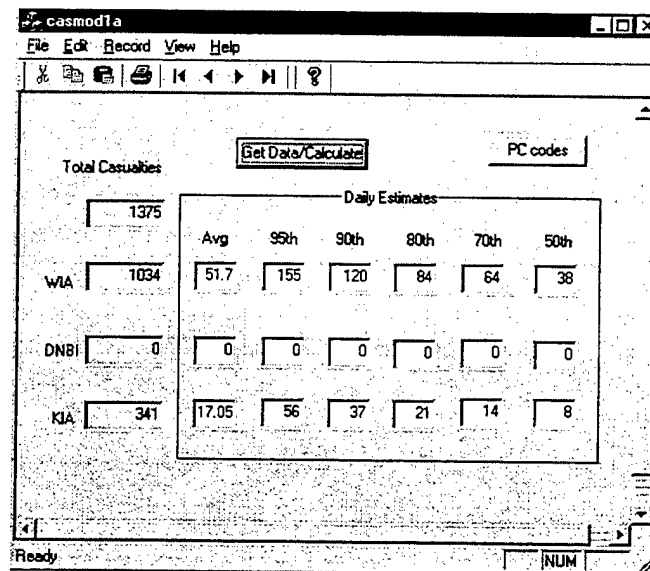


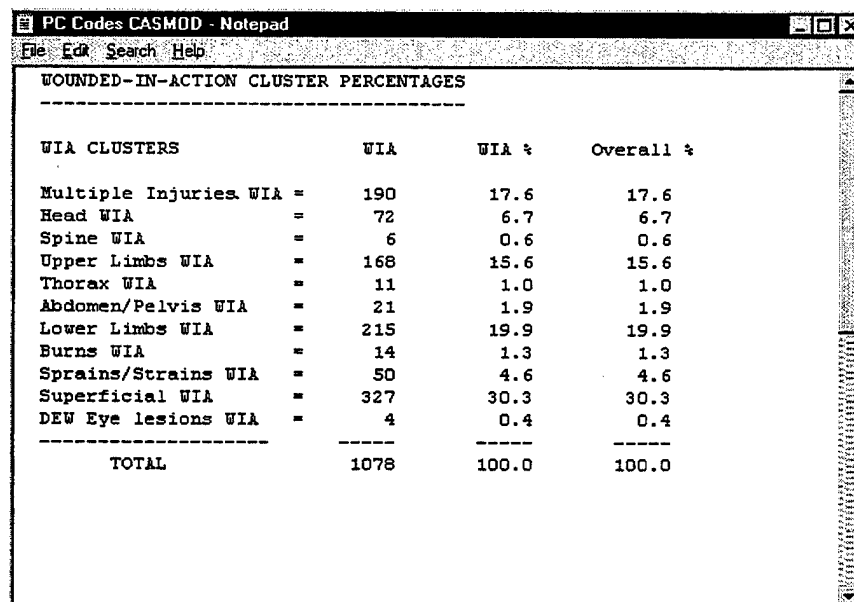
Figure 2. Casualty Rate Variability Module Output Screen

B. Patient Condition Code Module Compatible With CASEST

The second module reads the CASEST output file of the estimated number of WIA and DNBI casualties, and then projects the likely distribution of these casualties in terms of PC codes. After execution of a CASEST scenario, a report is generated that shows the estimated total number of casualties grouped by PC clusters and PC codes. The PC “clusters” are broad

categories of illness and injuries grouped largely along resource requirement lines. Individual PCs, such as PC 44 "fractured humerus" or PC 209 "dermatophytosis", allow for even greater specificity in determining the medical resources that may be needed.⁴ There are currently 349 PC codes for injuries or illnesses during sustained during conventional operations. While PC code nomenclature for casualties resulting from nuclear, biological, and chemical attacks have recently been added the projections of this module are limited to conventional injuries and illnesses. Narrative descriptions of each PC Code appear in an earlier report.⁵

To view the PC distribution report, the user clicks on the "PC codes" button on the CASMOD screen (Figure 2) and a report of the projected injury and illness distribution in terms of PC clusters is displayed which shows the individual PC codes. Figure 3 illustrates a sample PC cluster report percentage distribution. For example, of the total WIA casualties shown in Figure 1, approximately 6.7% of the injuries expected are to the head. Figure 4 presents the formatting for the individual PC code distribution within categories of WIA, DNBI, and battle fatigue (BF). This module also creates a data set of PC codes that can be exported into other applications for estimating supplies and other medical resources. A detailed description of the algorithms underlying the PC code distributions appears later in this report.



WOUNDED-IN-ACTION CLUSTER PERCENTAGES			
WIA CLUSTERS	WIA	WIA %	Overall %
Multiple Injuries WIA =	190	17.6	17.6
Head WIA =	72	6.7	6.7
Spine WIA =	6	0.6	0.6
Upper Limbs WIA =	168	15.6	15.6
Thorax WIA =	11	1.0	1.0
Abdomen/Pelvis WIA =	21	1.9	1.9
Lower Limbs WIA =	215	19.9	19.9
Burns WIA =	14	1.3	1.3
Sprains/Strains WIA =	50	4.6	4.6
Superficial WIA =	327	30.3	30.3
DEW Eye lesions WIA =	4	0.4	0.4
TOTAL	1078	100.0	100.0

Figure 3. Patient Condition Code Output Screen for Wounded-in-Action Clusters

PATIENT CONDITION CODES				
PC CODE	WIA	DNBI	BF	TOTAL
PC CODE 1	2	0	0	2
PC CODE 2	11	2	0	13
PC CODE 3	0	0	0	0
PC CODE 4	2	0	0	2
PC CODE 5	0	0	0	0
PC CODE 6	1	0	0	1
PC CODE 7	0	0	0	0
PC CODE 8	1	0	0	1
PC CODE 9	4	0	0	4
PC CODE 10	2	0	0	2
PC CODE 11	0	0	0	0
PC CODE 12	0	0	0	0
PC CODE 13	9	0	0	9
PC CODE 14	19	0	0	19
PC CODE 15	1	0	0	1
PC CODE 16	1	0	0	1
PC CODE 17	2	0	0	2
PC CODE 18	3	0	0	3
PC CODE 19	4	0	0	4

Figure 4. Output Screen for Individual Patient Condition Codes

C. FORECAS Casualty Rate Variability Enhancements

The FORECAS system was developed using Borland C++ Development Application 3.1, which operated in a disk operating system (DOS) environment and was recently migrated into a Windows platform. The underlying algorithms and source code were left unchanged but the graphical user interface was re-written to support the Windows operating system. The new platform was written in Visual C++ Version 6.0 using MFCs. A detailed discussion of FORECAS can be found in an earlier report documenting its statistical basis and use.²

To begin a simulation, the user must input the following parameters shown in Figure 5: casualty type, battle intensity, troop types, potential adversary, terrain and climate factors. After all user-defined parameters are input, the user may then proceed to view the output reports. Figure 6 displays the various menu options for viewing the output generated by FORECAS. Selection of the "Reports" option provides the user with projections of the WIA, KIA, and DNBI rates for the scenario that was entered; this option also provides mean, maximum, and minimum daily casualty loads projected for the scenario entered. Selection of the "PC Codes" option provides the same PC cluster and PC code output shown in Figures 3 and 4. Selection of the one of "Graph" option for one of the troop components provides a graphical display, such as that seen

in Figure 7, of the magnitude of the daily casualty rate spikes that can be expected for the entered scenario.

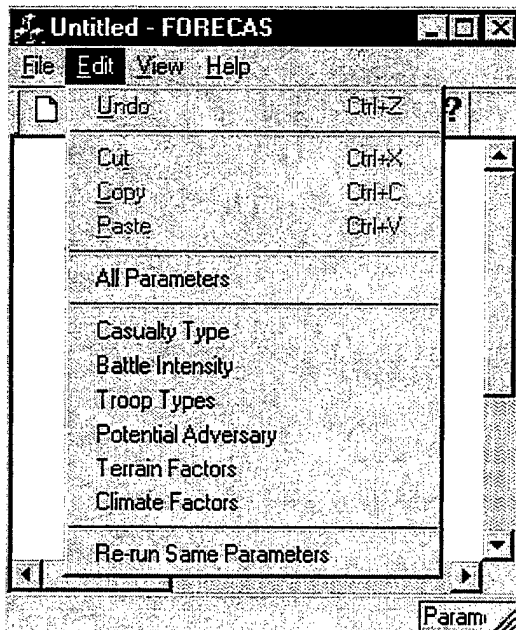


Figure 5. FORECAS Input Parameters

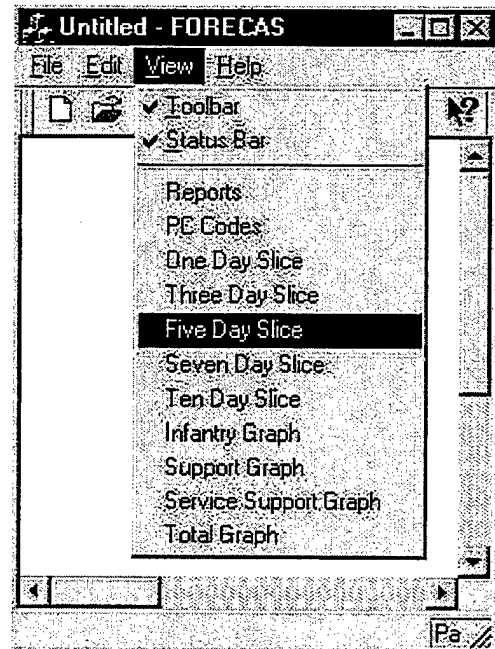


Figure 6. FORECAS Output Reports

Another indicator of the expected casualty rate variability during a combat operation is obtained by choosing one of the "Slice" options shown in Figure 6. Selection of the "Three Day Slice," for instance, provides the user with a range of variability projected among individual 3-day intervals for the military engagement. This feature allows the planner to gauge the range in casualty incidence expected for various temporal segments of an operation. Figure 8 shows that this option provides expected casualty rates corresponding to the 99th, 95th, 90th, 80th, 70th, 60th, 50th, and 30th percentile values. In the example given in Figure 8, on 95% of the days the WIA rate is projected to be less than 4.84. This option also provides the ratio of the mean rate to each percentile value to allow the medical planner to gauge the potential shortfall of a given supply (such as beds) if resources were based on expected mean values rather a value approaching the possible maximum daily casualty load. For example, the mean rate shown in Figure 8 is 1.89; hence, the ratio of the 95th percentile value was derived as the mean rate divided into the percentile rate ($4.84/1.89 = 2.57$). Thus, on 5% of the days, casualty incidence is projected to be at least two and half times the expected mean incidence.

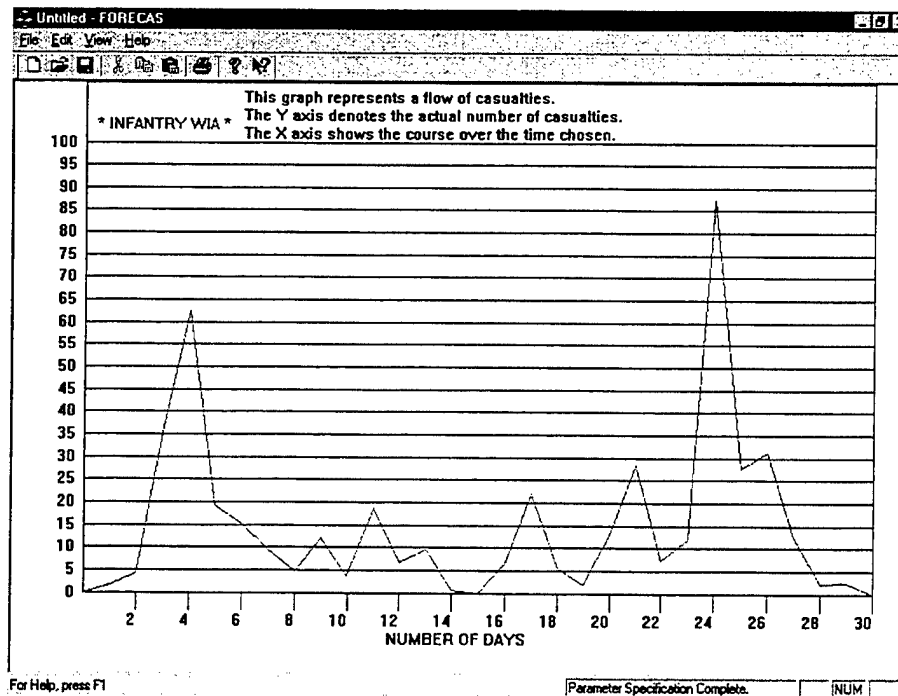


Figure 7. FORECAS Output Screen Showing Graphical Display of Expected Rate Variability

GROUND TROOP PERCENTILE RATES for Adversary X				
INFANTRY TROOPS	WIA	RATIO*	BF	RATIO*
99th percentile	8.81	4.67	2.20	5.84
95th percentile	4.84	2.57	1.21	3.21
90th percentile	3.45	1.83	0.86	2.29
80th percentile	2.54	1.35	0.51	1.35
70th percentile	2.09	1.11	0.42	1.11
60th percentile	1.67	0.88	0.33	0.88
50th percentile	1.47	0.78	0.29	0.78
30th percentile	0.98	0.52	0.15	0.39

Percentiles are based on 3-day slices per 1000 strength per day
 *WIA Ratio is calculated as percentile estimate divided by mean rate of 1.89

Figure 8. Output Screen in FORECAS Highlighting Casualty Rate Variability.

II. STATISTICAL UNDERPINNINGS

Previous research performed at the Naval Health Research Center has shown that distribution characteristics of casualty incidence patterns may be derived by fitting mathematical distributions to illness and injury data of previous operations.^{2,6} Specifically, the examination of individual combat and support units shows that historical WIA incidence data are best represented by single and batch arrivals in a nonhomogeneous Poisson process and can be simulated by an exponential distribution.⁶ Additionally, the simulation of historical DNBI rates can be derived from a lognormal distribution. Thus, these distributions provide a basis for determining percentile values when a mean value is known. Percentile values are calculated as the probability that the number of observations from the given distribution will be less than or equal to a specified value.

Percentile estimates can be calculated by using a cumulative distribution function, or can be based on randomly generated variates using the appropriate distribution function. Use of randomly generated variates provides the variability that is most likely to be observed in military operations, and thus is the method chosen for the present modeling purposes.

A. Percentile Estimates Based on Distribution Function for Proposed CASEST Module

After execution of a CASEST scenario an output file generates the total number of WIA, KIA, and DNBI casualties. The mean daily number of casualties is calculated by the new module based on the total number of casualties and length of the operational phase under study. The module then generates 400 random variates to calculate rates corresponding to various percentile values. Sample size calculations indicated that a minimum of 387 variates was needed for a 95% confidence level and a margin of error 0.05. For WIA and KIA casualties, an exponential distribution is used in generating the variates, and for DNBI casualties a lognormal distribution is used.

Exponential Distribution

X is random variable distributed exponentially:

$$X \sim \text{Exp}(\lambda) \text{ where } E(X) = 1 / \lambda$$

The probability density function (*p.d.f*) is defined as:

$$f(x | \lambda) = \lambda e^{-\lambda x}, \text{ where } x > 0$$

The cumulative distribution function (*c.d.f*) is obtained by taking the derivative of the *p.d.f*, which yields the following equation.

$$F(x | \lambda) = 1 - e^{-\lambda x}, \text{ where } x > 0$$

Simulation of the exponential distribution is accomplished by using the inverse transformation method. This is based on the proposition, let U be a uniform variable (0,1), and define random variable Y as the inverse of U, that is ($Y=F^{-1}(U)$). Then Y has distribution function F, where $F^{-1}(x)$ is defined to equal that value y for which $F(y)=x$. For example applying the inverse transformation to the *c.d.f* of the exponential distribution where F is defined as $F(x | \lambda) = 1 - e^{-\lambda x}$ is shown below.

$$\text{If } F(x) = 1 - e^{-x} \text{ then}$$

$$F^{-1}(u) = 1 - e^{-u}$$

$$x = -\ln(1 - u) \text{ (inverse of the } F(x)\text{)}$$

Thus, if U is a uniform (0,1) variable, then $F^{-1}(U) = -\ln(1-U)$ with mean 1. Since $1-U$ is also uniformly distributed on (0,1), it follows that $-\ln(U)$ is exponential with mean 1. If λX is exponential with mean λ when X is exponential with mean 1, it follows that $-\lambda \ln(U)$ is exponential with mean λ .⁸

Simulation of an exponential distribution can be easily accomplished on any scientific calculator with a random number generator. For demonstration purposes, below is an example of five simulated exponential variates with a mean of 5 where the uniform random variables (.104, .495, .405, .624, and .361) were obtained using a scientific calculator.

$$-\lambda * \ln(U)$$

$$-5 * \ln(.104) = 11.31$$

$$-5 * \ln(.495) = 3.52$$

$$-5 * \ln(.405) = 4.52$$

$$-5 * \ln(.624) = 2.36$$

$$-5 * \ln(.361) = 5.09$$

Lognormal Distribution

The lognormal distribution is simply a special case of the normal distribution. Each variate of the normal distribution is raised to the exponent power to generate the lognormal distribution.

$$\text{If } X \sim N(\mu, \sigma^2) \text{ then } Y = e^X \sim LN(\mu, \sigma^2)$$

Generating a lognormal distribution is accomplished by taking the exponent of each normal variate.

$$\text{If } Y = e^X, \text{ where } X \sim N(\mu, \sigma^2) \text{ then } Y \sim LN(a, b) \text{ where,}$$

$$a = \ln((\mu^2 / (\sigma^2 + \mu^2))^{1/2}),$$

$$b = \ln((\sigma^2 + \mu^2) / \mu^2),$$

Simulation of the normal distribution is accomplished by using the Box-Muller transformation, which generates normal variates in pairs.⁹ If U and V are independent uniform variables, then the variables A and B generate pairs of variates from a standard normal distribution population.

$$A = \sigma (-2 \ln U)^{1/2} \cos(2\pi V) + \mu$$

$$B = \sigma (-2 \ln V)^{1/2} \sin(2\pi U) + \mu$$

For example, eight simulated variates from $LN(1,2)$ where the shape and scale parameters, respectively, were arbitrarily chosen, can be obtained by (1) generating eight variates from a standard normal random variable, (2) adjusting the parameters of the shape and scale parameters of the lognormal distribution, (3) calculating the normal variates with the adjusted mean and standard deviation, and (4) taking each exponent of the normal variates.

Step 1. Eight independent uniform observations are generated in pairs of fours:

.4224 .9728 .8801 .4410

.0402 .2316 .9240 .5073

The first row is taken as the U's and the second as V's to obtain the normal variates.

A: 1.27 .027 .4489 -1.28

$$B: -.5822 \quad .2334 \quad -.2323 \quad .0587$$

Step 2. Adjust the two parameters of the lognormal distribution using the following formula:

$$a = \ln((\mu^2 / (\sigma^2 + \mu^2))^{1/2}) = \ln((1^2 / (2^2 + 1^2))^{1/2}) = -0.8047$$

$$b = \ln((\sigma^2 + \mu^2) / \mu^2) = \ln((2^2 + 1^2) / 1^2) = 1.609$$

Step 3. Eight normal variates are generated using the Box-Muller transformation where $a=\mu$, $b=\sigma$ and A, B are the standard normal variates.

$$X_1 = \mu + (\sigma * A_1) = -0.8047 + (1.609 * 1.27) = 1.24$$

$$X_2 = \mu + (\sigma * A_2) = -0.8047 + (1.609 * .0271) = -0.76$$

$$X_3 = \mu + (\sigma * A_3) = -0.8047 + (1.609 * .4489) = -0.08$$

$$X_4 = \mu + (\sigma * A_4) = -0.8047 + (1.609 * 1.28) = 1.25$$

$$X_5 = \mu + (\sigma * B_1) = -0.8047 + (1.609 * -.5822) = -1.74$$

$$X_6 = \mu + (\sigma * B_2) = -0.8047 + (1.609 * .2334) = -0.43$$

$$X_7 = \mu + (\sigma * B_3) = -0.8047 + (1.609 * -.2323) = -1.18$$

$$X_8 = \mu + (\sigma * B_4) = -0.8047 + (1.609 * 0.587) = 0.14$$

Step 4.

Take exponent of each normal variate to obtain the eight random variables of a LN(1,2).

$$e^{X_1} = \exp(1.24) = 3.45 \quad e^{X_5} = \exp(-1.74) = 0.17$$

$$e^{X_2} = \exp(-0.76) = 0.47 \quad e^{X_6} = \exp(-0.43) = 0.65$$

$$e^{X_3} = \exp(-0.08) = .92 \quad e^{X_7} = \exp(-1.18) = 0.31$$

$$e^{X_4} = \exp(1.25) = 3.50 \quad e^{X_8} = \exp(0.14) = 1.15$$

Percentile Function

The n th percentile is defined to be the point such that $n\%$ of the expected casualty rates fall below the rate corresponding to this percentile. For each attrition type (WIA, KIA, DNBI), 400 variates are generated and stored in an array. The array is sorted and the percentile estimates are calculated using the formula shown below. Percentiles can be estimated from N measurements by setting $1+p(N-1)$ equal to $k+d$ for k an integer, and d , a fraction greater than or equal to 0 and less than 1.

$$Y(p) = Y[k] + d(Y[k+1] - Y[k]), \text{ where}$$

p = the percentile value

N = the number of elements

Y[k] = The kth element in an array where Y₁, ... Y_N is ordered in increasing order

For k=0, Y(p)=Y[1]

d = (1 + p (N-1)) - floor((1 + p (N-1))) where the floor function is the integer round-down of the value (1 + p (N-1))

For example, determination of the 90th percentile for 400 measurements would yield the following parameters, $1 + p(N-1) = 1 + .90 * (400-1) = 360.1$; $k = 360$ and $d=.1$. From the above formula the following equation becomes, $Y(.90) = Y[360] + .1*(Y[361] - Y[360])$.

B. Simulating Rate Variability of Temporal Slices in FORECAS Model

Recently incorporated into FORECAS, this function, described earlier in this report, allows the user to calculate percentile estimates of rate variability for temporal slices of the operation. The program derives 400 variates of daily casualty rates projected for the operation based on the mean casualty rate and the appropriate rate distribution calculated from the user-specified input parameters. Thus, if a 5-day temporal slice were selected from the output menu, FORECAS would first generate 400 five-day casualty rate patterns projected for the user-defined operation, and then compute a mean for each of those 5-day series and sequentially orders these means. Once these new means are sequentially ordered, FORECAS outputs the values associated with the 99th, 95th, 90th, and other percentile values. The algorithm for deriving the means for each temporal slice is as follows:

$$F_{(i)} = \frac{1}{N} \sum_{j=1}^N A_j \quad \text{where } i = 1 \text{ to } 400$$

F_i = is the forecasted value for each temporal slice

N = number of days the user wants to estimate percentile estimates

A_j = sum of the values based on the temporal slice

j = 1, 3, 5, 7, and 10 are the slice options

C. Simulation of the PC Code Distribution for Both CASEST and FORECAS

Generating a patient stream in terms of the expected PCs is accomplished by the program reading the numbers of overall casualties (WIA, DNBI) projected from a CASEST or FORECAS simulation. These overall numbers are then used in conjunction with tables of PC code distributions that may be incorporated into CASEST and FORECAS. Multiplication of the total number of admissions by each PC code percentage yields an expected mean number of occurrences for each PC code. Using this expected mean number, a Poisson random variable is used to project the number of occurrences for each PC code. An advantage of using the Poisson distribution is that it eliminates rounding errors since it is a discrete distribution function. However, because the Poisson is a stochastic process, in most instances the sum of all the PC codes will be slightly higher or lower than the number of casualties originally generated by FORECAS or CASEST.

The simulation of PC code occurrences is accomplished by applying a mean rate λ to a Poisson random variable. To simulate a Poisson random variable with mean λ , independent uniform random variables, U_i are generated between (0,1) stopping when the product falls below $e^{-\lambda}$.

The following formula is used to generate discrete occurrences of PC codes given a mean rate:

$$N = \min \{ n : \prod_{i=1}^n U_i < e^{-\lambda} \}$$

If the generation of random numbers is continued until the product falls below $e^{-\lambda}$, then the number required to satisfy the condition, minus 1, is Poisson with mean λ .⁸ The random variable, $X = N-1$, then has the desired distribution.

Example Simulating a Poisson Random Variable With Given Mean Rate $\lambda = 5$:

$$e^{-\lambda} = .0067$$

- 1: (.220) < .0067 (Condition not met, continue)
- 2: (.220 * .066 = .01452) < .0067 (Condition not met, continue)
- 3: (.220 * .066 * .519) = .0075 < .0067 (Condition not met, continue)
- 4: (.220 * .066 * .519 * .948) = .0071 < .0067 (Condition not met, continue)
- 5: (.220 * .066 * .519 * .948 * .822) = .0058 < .0067 (Condition met, stop)

The simulated number for this example would be $X = 5 - 1 = 4$. The random numbers (.220, .066, .519, .948, and .822) were generated using a scientific calculator for this example.

CONCLUSION

Two modules have been developed for use in conjunction with the CASEST casualty system and the FORECAS ground casualty model to allow for more refined estimates of the expected medical admissions. For projecting certain medical resource needs, such as beds, where there may be dramatic fluctuations in the daily demands, planning should be based on a percentile rate thought to optimally balance considerations of oversupply with the need to ensure adequate supply during periods of mass patient loads. The first new module provides the medical planner with the casualty numbers that may be expected during peak periods of military operations. The second module translates the projected overall number of admissions into the likely distribution of medical admissions by specific Patient Condition codes. Medical resource planners will be able to gauge the resources needed by taking into consideration the anticipated peaks of daily casualty incidence and the specific medical conditions likely to be sustained. Combining the expected PC code distributions with the projected overall casualty incidence now allows planners to more accurately project medical resource requirements.

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REPORT DOCUMENTATION PAGE

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13. SUPPLEMENTARY NOTES

14. ABSTRACT (maximum 200 words) Models used to project ground casualties for military operations typically provide estimates of the average number of daily casualties without indicating the magnitude of the likely casualty spikes or the specific types of illnesses and injuries that will be sustained. The expected casualty spikes are needed since resources such as hospital beds and medical personnel could be underestimated and should be based on estimates greater than the average likely patient load. Estimates of the types of medical conditions likely to be seen are also needed since the specific medical supplies needed to treat a patient may differ greatly depending upon the particular wound or disease incurred. The present effort documents casualty simulation technologies that can be used for assessing the daily casualty incidence variability and projecting the composition of a patient stream in terms of the specific traumas and illnesses that may be observed during military operations.

15. SUBJECT TERMS casualty projections, wounded-in-action, disease, non battle injuries, simulation techniques, medical planning, patient condition codes, FORECAS, CASEST

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